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TENSILE-STRENGTH INVESTIGATION OF CAST-IRON PISTON RINGS OF VARIOUS STRENGTHS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

TENSILE-STRENGTH INVESTIGATION OF CAST-IRON PISTON RINGS OF VARIOUS STRENGTHS

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SUMMARY

Tensile tests were made of NACA microtensile specimens of 0.050-inch diameter sectioned from finished cast-iron piston rings. Tests were also made on NACA microtensile and bar specimens sectioned from castings of 45,000 and 70,000 pounds per square inch nominal tensile strength. Photomicrographs are presented in the report to show the relation between graphite-flake size and tensile strength and radiographs are given to show shrinkage cavities in finished piston rings.

Tests of NACA microtensile specimens from finished piston rings of various nominal tensile strengths showed the following results:

Nominal tensile strength (lb/sq in.)	Average tensile strength from NACA microtensile tests (lb/sq in.)
45,000	38,000 to 43,000
68,000	68,900
70,000	57,000 to 63,000

In general, the test results of NACA microtensile specimens were somewhat lower than the test results from bar specimens sectioned from the same castings.

The metallographic examination showed that the lower strengths were accompanied by larger graphite-flake sizes. Shrinkage cavities had an adverse effect on the tensile strength of cast-iron rings of 95,000 pounds per square inch nominal tensile strength, as shown in radiographs and photomicrographs.

The use of the NACA microtensile specimens in a tensile-strength investigation has the advantage of permitting the use of finished

piston rings which have been cast in a production manner. On the basis of the agreement of test results from NACA microtensile specimens with results from bar specimens, it is believed that the tests on NACA microtensile specimens obtained from all portions of the castings or rings give representative tensile strengths.

INTRODUCTION

As the power of an aircraft engine is increased, the precision of construction and the quality of every engine part must be improved. The piston rings are one of the first parts to fail as the operating loads and temperatures in an engine cylinder are increased. The type of failure varies from scuffed and feathered rings, which result in high oil consumption, to stuck and broken rings. One of the important properties of the piston rings from a consideration of the resistance to breakage is the tensile strength of the ring material. The wear properties of piston-ring materials may vary appreciably with tensile strength but resistance to wear is more dependent on other factors.

An investigation of the tensile strength of cast-iron piston rings was conducted early in 1944 at the NACA Aircraft Engine Research Laboratory. The primary object of the investigation was to determine the tensile strength of cast-iron piston rings of various nominal tensile strengths. A secondary object was to compare the NACA microtensile method of testing with the standard tensile-bar method of testing piston-ring materials. The investigation was concerned only with the tensile strength of the rings and the effect of microstructure on tensile strength.

Because of the nature of cast iron, the physical characteristics of the material are dependent to a large extent upon foundry treatment. The problem therefore arose of how to investigate the material on the basis of its ultimate tensile strength. One method in current use consists in making special test castings having straight sections that can be used as tensile specimens. This standard method was one of the two used in this investigation. The second method, developed at the NACA, utilizes microtensile test specimens small enough to be sectioned from finished piston rings. This second method has the advantage of permitting the use of piston rings cast in a production manner; the results of this method should therefore be representative of the tensile strengths of piston-ring materials in the finished piston-ring condition. In comparison with usual cast irons, piston-ring cast irons have relatively small graphite flakes; it is therefore believed that microspecimens should be suitable for tensile tests of piston-ring materials.

Microtesting of steel and iron has been the object of much discussion. In reference 1, a method of testing microtensile specimens is described in a study of welds where microtensile specimens of 0.059-inch diameter were sectioned from various zones of steel welds. Eugene (reference 2) has described a method of testing small cast-iron specimens of 0.222-inch diameter in production control of a cast-iron foundry. Each author states that his method of testing microspecimens of homogeneous materials is comparable with standard test methods within the expected scatter of results for cast irons. Draffin and Collins (reference 3) state that this scatter may vary as much as 10 to 11 percent for iron castings from the same pouring.

TEST SPECIMENS AND APPARATUS

Specimens. - Two types of tensile specimen were used: the bar specimen (fig. 1(a)), which is a specimen generally used by ring manufacturers in determining tensile strength; and the NACA microtensile specimen (fig. 1(b)). The NACA microtensile specimen is approximately one-tenth the size of a standard A.S.T.M. 0.505-inch-diameter tension-test specimen for cast iron; however, a longer proportionate distance was left between the reduced area and the thread. The increased length was required for greater ease in handling the small test specimens.

The bar specimens were machined from the straight sections of the test castings (fig. 2). The NACA microtensile specimens were sectioned from (1) the curved sections remaining after the straight sections had been removed from the test castings (fig. 3(a)); (2) the unfinished rough bar specimens (fig. 2(b)); (3) the machined bar specimens (fig. 3(b)); and (4) the miscellaneous finished piston rings (fig. 3(c)). The difference between the number of specimens prepared and the number for which test results are reported resulted from the fact that some specimens broke outside the gage length.

The diameters at the gage length of the specimens were measured on a pedestal comparator to the nearest 0.0001 inch. Two perpendicular diameters were measured. These diameters were averaged in order to obtain the diameter used for calculating the cross-sectional areas.

Radiography. - In order to obtain reliable results it was found desirable to radiograph all materials before machining into tensile specimens. The location of defective areas in the castings or rings was detected by radiographs and specimens were selected from both defective and solid sections to test their respective properties. Figures 4 and 5 are radiographs of finished cast-iron rings having a nominal tensile strength of 95,000 pounds per square inch. Ring AE-2 (fig. 4) and ring AE-10 (fig. 5(b)) had shrinkage cavities; ring AE-7 (fig. 5(a)) was free from such defects.

Testing machine and holders. - The bar specimens were tested on a 120,000-pound-capacity universal hydraulic testing machine using the 6000-pound range of loading. A pair of 10,000-pound-capacity Templin grips was used to hold the specimens. (See fig. 6.)

The NACA microtensile specimens were tested on another 120,000-pound-capacity universal hydraulic testing machine using the 1200-pound range of loading. Specially designed universal joints were used in testing small specimens. The joints were alined until eccentricity was reduced to a minimum. One end of each holder was tapped for the spherical seating bolt used with the Templin grips. The other end was tapped to hold the threaded specimen. Figure 7 shows the holders and the NACA microtensile specimen.

TEST PROCEDURE

Two series of tests were made. In the first series, the tensile strengths of NACA microtensile specimens from finished piston rings were compared with nominal tensile strengths. In the second series, the tensile strengths of NACA microtensile and bar specimens sectioned from special castings were compared with each other and with the nominal tensile strengths.

The actual procedure for running the tensile tests was similar to the procedure for testing standard-size specimens. A rate of loading of 90 pounds per minute was used in testing the NACA microtensile specimens and a rate of loading of 750 pounds per minute was used in testing the bar specimens. Both rates of loading were chosen to give approximately the same stress increase per unit time.

Tests of NACA microtensile specimens from finished piston rings. - Tests of NACA microtensile specimens from finished rings were made for comparison with the manufacturer's nominal tensile strength of their ring materials. Tests were made of cast irons of 45,000, 68,000, 70,000, 80,000 and 95,000 pounds per square inch nominal tensile strength.

Tests of NACA microtensile specimens and bar specimens. - The tests of NACA microtensile and bar specimens were made on the following cast-iron samples:

(a) 70,000 pounds per square inch nominal, as cast and heat treated

(b) 70,000 pounds per square inch nominal, machined tensile bars

(c) 45,000 pounds per square inch nominal, rough bar specimens from test castings

Six NACA microtensile specimens and two bar specimens were sectioned from each casting of 70,000 pounds per square inch cast iron. Two samples of as-cast and four of heat-treated castings were tested. Of 17 bar specimens received from the ring manufacturer, 10 were tested as bar specimens. The other 7 were sectioned into 3 NACA microtensile specimens each (fig. 3(b)) giving a total of 21 NACA microtensile specimens.

Out of 10 rough bar specimens, 7 from castings of nominal 45,000 pounds per square inch cast iron were machined into finished bar specimens; 9 NACA microtensile specimens were machined from the other 3 rough bar specimens (fig. 3(b)).

Accuracy of tests. - The accuracy of the diameter measurements by the pedestal comparator was ±0.5 percent. The accuracy of tensile tests on bar specimens was ±0.5 percent in the range of testing (1000 to 2200 lb). The accuracy of tensile tests on NACA microtensile specimens was low, before correction, in the range of testing (50 to 200 lb). A calibration curve (fig. 8) was determined for the 1200-pound range of the 120,000-pound universal testing machine for loads from 20 to 260 pounds. Test loads were corrected to within ±1 percent of the true values using the following formula:

$$\text{actual load} = \text{machine reading}\left(1 - \frac{\text{percentage error}}{100}\right)$$

The over-all accuracy of testing after correction was within ±2 percent.

Metallography. - In order to determine the effect of the microstructure of the cast irons on the test results, photomicrographs were taken of unetched and etched specimens at a magnification of 200 diameters. The specimens were prepared by rough polishing successively on No. 2 through No. 000 grit emery papers. The specimens were finish-polished first on a wax lap impregnated with 600 grit alumina, next on a paraffin lap with levigated alumina, and last on a velveteen cloth using magnesium oxide. Specimen etching was done with a 4-percent picral solution.

RESULTS AND DISCUSSION

Tests of NACA microtensile specimens from finished piston rings. - The results of tests of NACA microtensile specimens from finished piston rings are shown in table I and figure 9. The cast iron of 95,000 pounds per square inch nominal tensile strength gave widely varying results. A radiograph (fig. 4) shows that ring AE-2 had much shrinkage porosity. Results of these tests were consequently low. Although ring AE-7 (fig. 5(a)) was free of defects, tensile-test results indicate that this ring had a low tensile strength. Ring AE-10 was radiographed before testing (fig. 5(b)) and specimens were selected from both defective and solid sections. The widely varying results proved that a choice of sections is very important. Tensile-test results in the defect-free sections of ring AE-10 check closely with the nominal tensile value, whereas the specimens having shrinkage cavities showed low tensile strength. (See table I and fig. 9.)

Results for ring AF-2 (nominal tensile strength, 80,000 lb/sq in.) were low. Because this ring was not radiographed before testing, it is not known whether defects were responsible for the low values.

Results obtained on the cast-iron rings of 68,000 pounds per square inch nominal tensile strength showed an average tensile strength of 68,900 pounds per square inch. The average results of the $5\frac{1}{2}$-inch-diameter rings of 70,000 pounds per square inch nominal tensile strength fell below the nominal value. Average tensile values for the miscellaneous stock rings fell slightly below the nominal tensile strength of 45,000 pounds per square inch.

Tests of NACA microtensile specimens and bar specimens. - The tests of NACA microtensile specimens and bar specimens (table II and fig. 10) indicate that the tensile strengths of the NACA microtensile specimens were 5.6 to 10.6 percent lower than the tensile strengths of the bar specimens. A 9.2-percent difference in average tensile strengths between NACA microtensile and bar specimens was found for specimens machined from as-cast castings of 70,000 pounds per square inch nominal tensile strength. A 10.6-percent difference in average tensile strength between NACA microtensile and bar specimens was found for specimens machined from heat-treated castings of 70,000 pounds per square inch nominal tensile strength. These differences resulted from the fact that NACA microtensile specimens were sectioned from both weak and strong portions of the casting, whereas the bar specimens were sectioned from only the strongest portions. The test castings were so designed that the gates were at the large arcs of the casting (as shown in fig. 2). The areas in the proximity of the gates and risers probably have a great heterogeneity of structure because of the lower cooling rates induced by the resulting heavy section. The tensile strengths of the specimens sectioned from these areas therefore have the greatest spread and the lowest average values.

The results of the tests on nominal 70,000 pounds per square inch finished bar specimens support the explanation offered in the previous paragraph for the difference in average tensile strength between NACA microtensile and bar specimens. In these tests, NACA microtensile specimens were actually sectioned from bar specimens and comparisons were made only on the basis of strong sections. A difference in tensile strength between NACA microtensile and bar specimens of 4000 pounds per square inch (5.6 percent) resulted from these tests.

The tests of bar specimens of 45,000 pounds per square inch nominal tensile strength indicated a difference between NACA microtensile and bar specimens of 4000 pounds per square inch (8 percent).

Based on the agreement of test results from NACA microtensile specimens with results from bar specimens, it is believed that the tests on NACA microtensile specimens obtained from all portions of the castings or rings give representative tensile strengths.

Table II shows that the range of tensile strengths for bar specimens was relatively narrow when only two bars were tested for each set of average values. When seven or eight bars were tested for each set of average values, the range of tensile strengths was much wider.

The range of values was wider for microtensile tests than for bar tests from each casting but, in each case, a greater number of microtensile tests was run. The range of tensile values for an equal number of tests is approximately the same for NACA microtensile and bar specimens. An explanation for the wide range of values obtained in the microtensile tests may lie in the varying graphite-flake size of the NACA microtensile test specimens.

<u>Metallographic study.</u> - The average tensile strengths obtained from tests of a number of NACA microtensile specimens from each test casting checked favorably with values obtained from bar tests run at AERL or by the ring manufacturers. Individual AERL tests, however, varied as much as 40 percent in some cases, whereas the general range of reproducibility of results of standard tests on cast irons from the same pouring is stated in reference 3 to be 10 to 11 percent. The variation in the AERL tests may have been due to differences in

the graphite-flake size of the NACA microtensile-test specimens. Differences in graphite-flake size have more effect on test results for microtensile specimens than for bar specimens because the graphite flakes take up more proportionate area in the small than in the large specimens. Differences in graphite-flake size were observed by examining and comparing polished cross sections of NACA microtensile specimens of high and low tensile strengths from castings, bars, and rings. In general, for cast irons of 45,000, 68,000, and 70,000 pounds per square inch nominal tensile strengths, the specimens of high tensile strength showed finer graphite-flake sizes than the specimens of low tensile strength. (See figs. 11 to 17.) The NACA microtensile tests on cast iron of 95,000 pounds per square inch nominal tensile strength showed that low tensile strengths were obtained when shrinkage porosity was present at the fracture of the tested specimens. (See fig. 17.)

Figures 11, 12, and 13 illustrate the structural differences between low-strength and the high-strength specimens of as-cast and heat-treated cast irons of 70,000 pounds per square inch nominal tensile strength. The large graphite flakes in the low-strength specimens indicate that large flake size was probably the cause of the low-strength values of these cast irons. When the specimens were etched with 4-percent picral to determine if any additional differences in structure could be observed, disregarding graphite flakes, no other important differences in structure were found. (See figs. 11 to 17.)

Figure 14 (cast-iron ring specimens of 68,000 lb/sq in. nominal tensile strength) also substantiates the fact that large graphite flakes reduced the tensile strength. Figures 15 and 16 (cast-iron ring specimens of 45,000 lb/sq in. nominal tensile strength) show a difference in flake size but the difference is not so outstanding as shown in the previous figures. It should be noted, however, that the differences in tensile strength are not so great as they were in the higher-strength cast irons. Because the tensile strengths for cast iron of 45,000 pounds per square inch nominal tensile strength fell close to each other in most tests, it is believed that the 45,000 pounds per square inch nominal tensile strength material has a more homogeneous structure than the cast iron of 70,000 pounds per square inch nominal tensile strength.

The effect of shrinkage cavities on tensile strength is shown in figure 17. Figure 17(a) shows shrinkage cavities in a low-strength test specimen that was sectioned from a finished piston ring of 95,000 pounds per square inch nominal tensile strength; tests showed that this specimen had a tensile strength of 60,600 pounds per square inch. Figure 17(b) shows an almost defect-free specimen that was sectioned from the same ring; this specimen gave a test value of 95,000 pounds per square inch.

SUMMARY OF RESULTS

Results of tests of NACA microtensile specimens from finished cast-iron piston rings of various nominal tensile strengths showed that:

1. The rings of 95,000 pounds per square inch nominal tensile strength were greatly affected by shrinkage cavities. Average results as high as 90,300 pounds per square inch, however, were obtained by testing known defect-free areas of one ring.

2. The ring of 80,000 pounds per square inch nominal tensile strength gave an average value of 71,300 pounds per square inch. No radiographs were made of this ring and it is not known if shrinkage cavities were responsible for the low tensile values.

3. The rings of 68,000 pounds per square inch nominal tensile strength gave an average of 68,900 pounds per square inch.

4. The rings of 70,000 pounds per square inch nominal tensile strength gave an average value of 59,900 pounds per square inch.

5. Various rings of 45,000 pounds per square inch nominal tensile strength gave average values slightly below the nominal tensile strength.

6. Metallographic examination of high-strength and low-strength specimens from given castings, bars, and rings showed that specimens with larger graphite flakes had lower tensile strengths. No other important structural differences were observed.

Results of tests of NACA microtensile and bar specimens from cast irons of 70,000 and 45,000 pounds per square inch nominal tensile strength showed that:

1. The NACA microtensile specimens from as-cast test castings of 70,000 pounds per square inch nominal tensile strength gave a tensile strength 9.2 percent lower than the tensile strength of the bar specimens. The heat-treated test castings of 70,000 pounds per square inch nominal tensile strength gave a tensile strength 10.6 percent lower for the NACA microtensile specimens than for the bar specimens. These differences can be largely attributed to the fact that some NACA microtensile specimens were machined from low-strength sections.

2. The NACA microtensile specimens from finished bars of 70,000 pounds per square inch nominal tensile strength gave a tensile strength 5.6 percent lower than the tensile strength of the bar specimens.

3. The NACA microtensile specimens from rough bars of 45,000 pounds per square inch nominal tensile strength gave a tensile strength 8 percent lower than the tensile strength of the bar specimens.

4. The results of the tests run at AERL on bar specimens of 70,000 and 45,000 pounds per square inch nominal tensile strength checked closely with the results of bar-specimen tests made by the manufacturer.

The use of the NACA microtensile specimens in a tensile-strength investigation has the advantage of permitting the use of finished piston rings which have been cast in a production manner. Based on the agreement of test results from NACA microtensile specimens with results from bar specimens, it is believed that the tests on NACA microtensile specimens obtained from all portions of the castings or rings give representative tensile strengths.

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REFERENCES

1. Portevin, Albert M.: Micro Testing Machines for the Study of Welds. Metal Progress, vol. 28, no. 1, July 1935, pp. 49-51.

2. Eugene, Felix: A Universal Machine for Testing Cast Iron. Bulletin de la Societe d'Encouragement pour L'Industrie Nationale, vol. 134, Dec. 1935, pp. 609-612.

3. Draffin, J. O., and Collins, W. L.: The Tensile Strength of Cast Iron. A.S.T.M. Proc., vol. 37, pt. II, 1937, pp. 88-97.

TABLE I

TESTS OF NACA MICROTENSILE SPECIMENS FROM FINISHED PISTON RINGS

Nominal tensile strength (lb/sq in.)	Ring designation	Type of piston ring: Face	Type of piston ring: Nominal diameter (in.)	Number tested	Range of values (lb/sq in.)	Average tensile strength (lb/sq in.)
95,000	AE-2		$6\frac{1}{8}$	4	60,600-76,400	69,700
	AE-7			6	74,900-86,700	80,500
	AE-10			7	81,900-98,200	90,300
	AE-10			[a]2	57,100-59,600	58,300
80,000	AF-2		$6\frac{1}{8}$	4	62,600-78,400	71,300
66,000	ZY-1		$5\frac{1}{2}$	4	62,200-85,300	71,400
	ZZ-1			4	58,300-72,300	66,400
						68,900 Average
70,000	1		$5\frac{1}{2}$	4	50,100-73,400	62,900
	2			4	53,500-62,800	56,900
						59,900 Average
45,000	———		$5\frac{1}{2}$	3	40,800-43,800	42,300
	C-5	Taper	$5\frac{1}{2}$	3	34,000-41,300	38,500
	B-20	Beveled	$5\frac{1}{2}$	4	31,200-41,300	37,900
	G-23	Chrome-plated	$6\frac{1}{8}$	4	42,100-43,700	42,900
	F-23	Flat	$6\frac{1}{8}$	4	40,700-42,500	41,500

[a]Sections show shrinkage cavities.

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TABLE II

TESTS OF NACA MICROTENSILE AND BAR SPECIMENS

Cast iron		Casting number	NACA microtensile specimens			Bar specimens			Difference between NACA microtensile and bar specimens (percent reduction) (a)
Nominal strength (lb/sq in.)	Type		Number tested	Range of tensile strength (lb/sq in.)	Average tensile strength (lb/sq in.)	Number tested	Range of tensile strength (lb/sq in.)	Average tensile strength (lb/sq in.)	
70,000	As-cast castings	1	5	46,400-56,800	50,900	2	56,100-58,000	57,100	9.2
		2	3	50,500-54,900	52,500	2	55,800-56,700	56,300	
					51,500 Average			56,700 Average	
70,000	Heat-treated castings	1	6	55,400-74,500	64,700	2	68,500-76,500	72,500	10.6
		2	5	62,600-76,400	66,400	2	69,700-72,100	70,900	
		3	4	54,300-66,600	59,800	2	64,300-65,700	65,000	
		4	6	52,500-70,600	59,300	2	68,800-74,400	71,600	
					62,500 Average			70,000 Average	
70,000	Bar specimens	----	20	56,400-75,300	67,100	8	60,000-78,100	71,100	5.6
45,000	Bar specimens	----	9	43,800-51,900	46,100	7	40,100-58,200	50,100	8.0

[a]Based on the bar-specimen strength.

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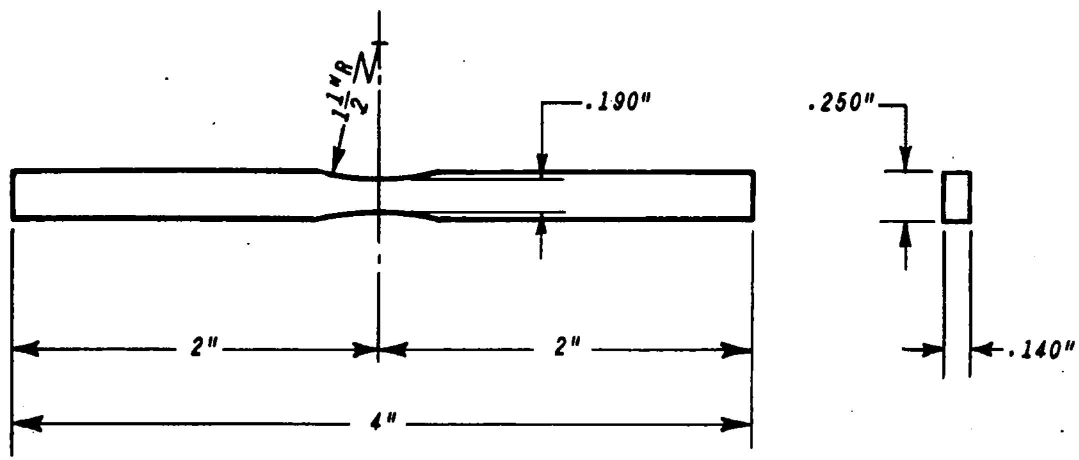
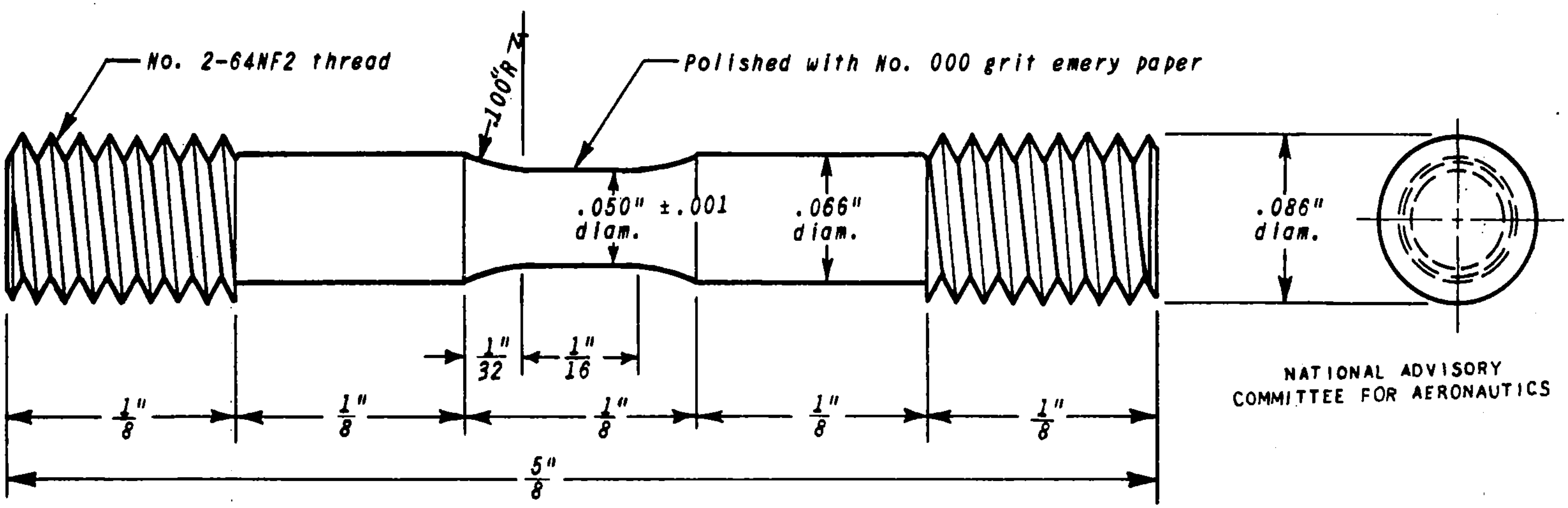


(a) Bar specimen. Actual size.



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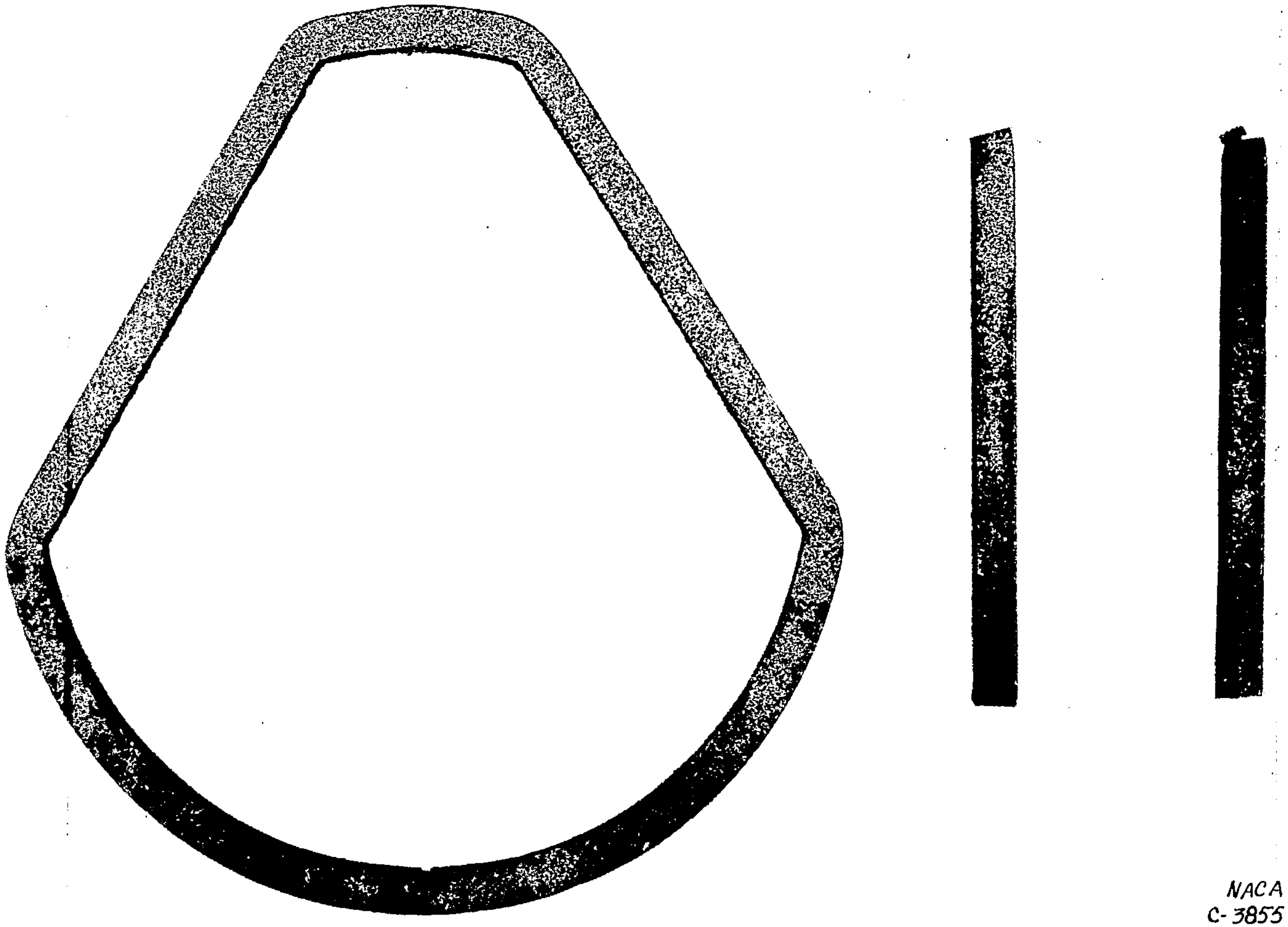
(b) NACA microtensile specimen. X10.

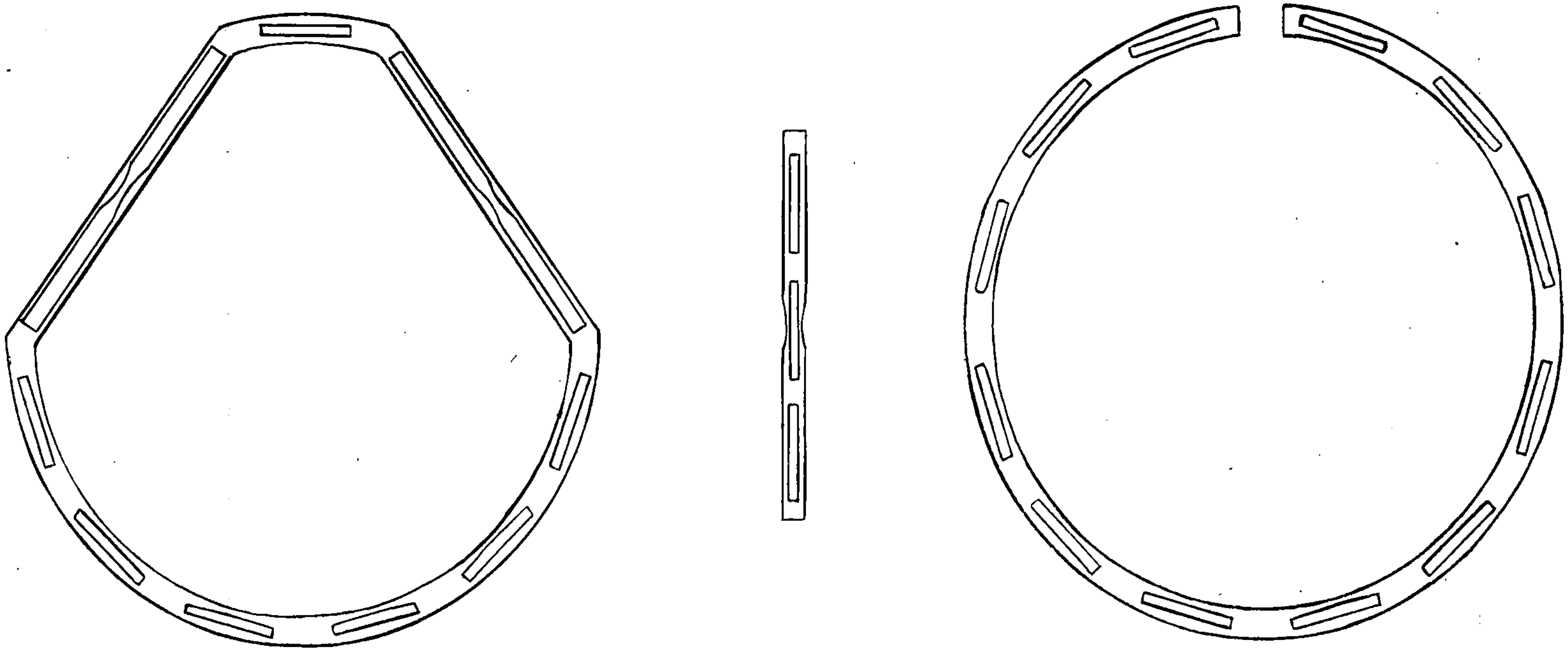
Figure 1. - Bar and NACA microtensile test specimens.



Gate

(a) Test casting. (b) Rough bar specimens

Figure 2. - Test casting and rough bar specimens approximately $\frac{3}{4}$ actual size



(a) Test casting. (b) Bar specimen. (c) Piston ring.

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Figure 3. - Location of NACA microtensile and bar specimens taken from test castings, bar specimens, and finished piston rings.

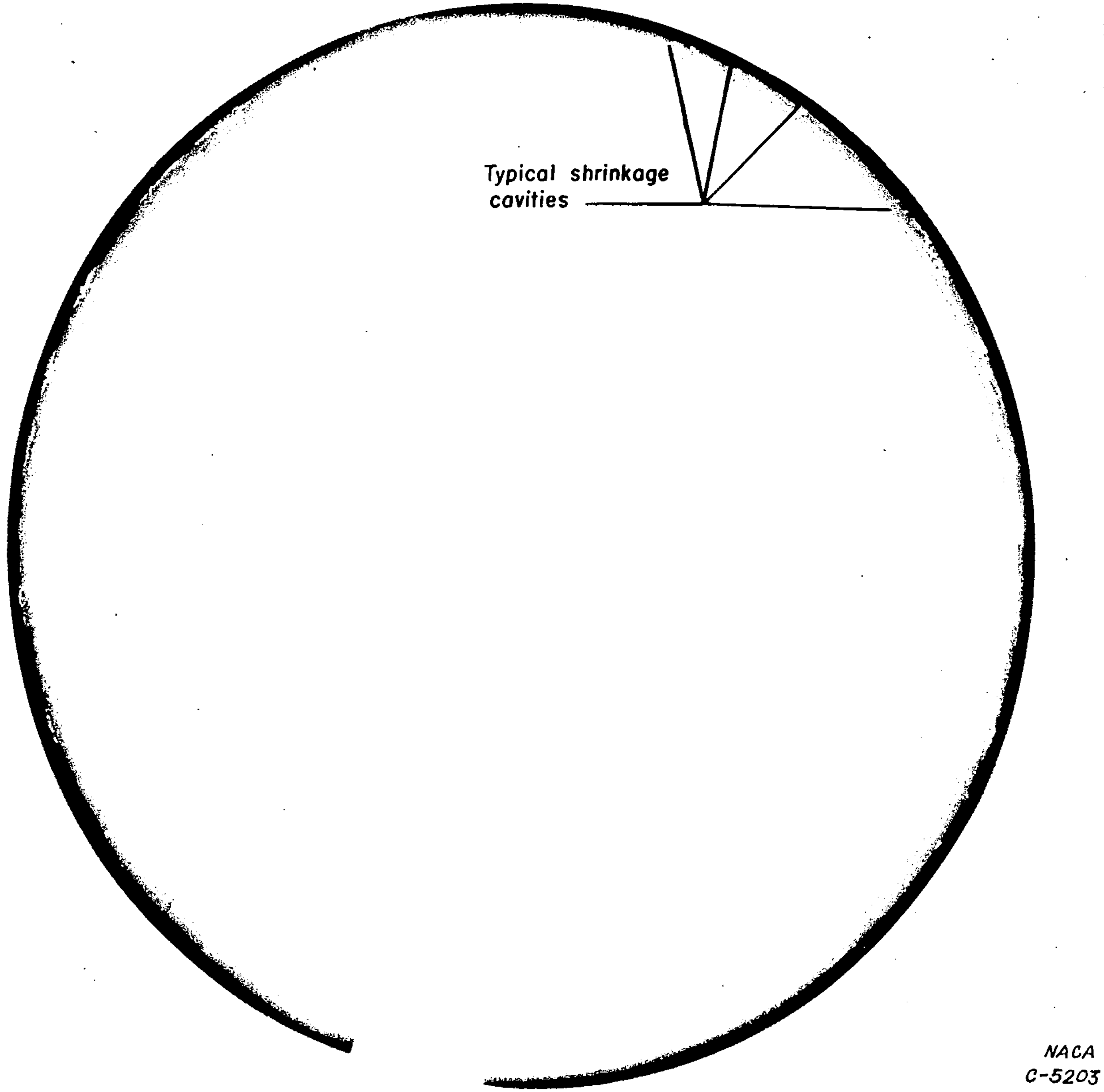
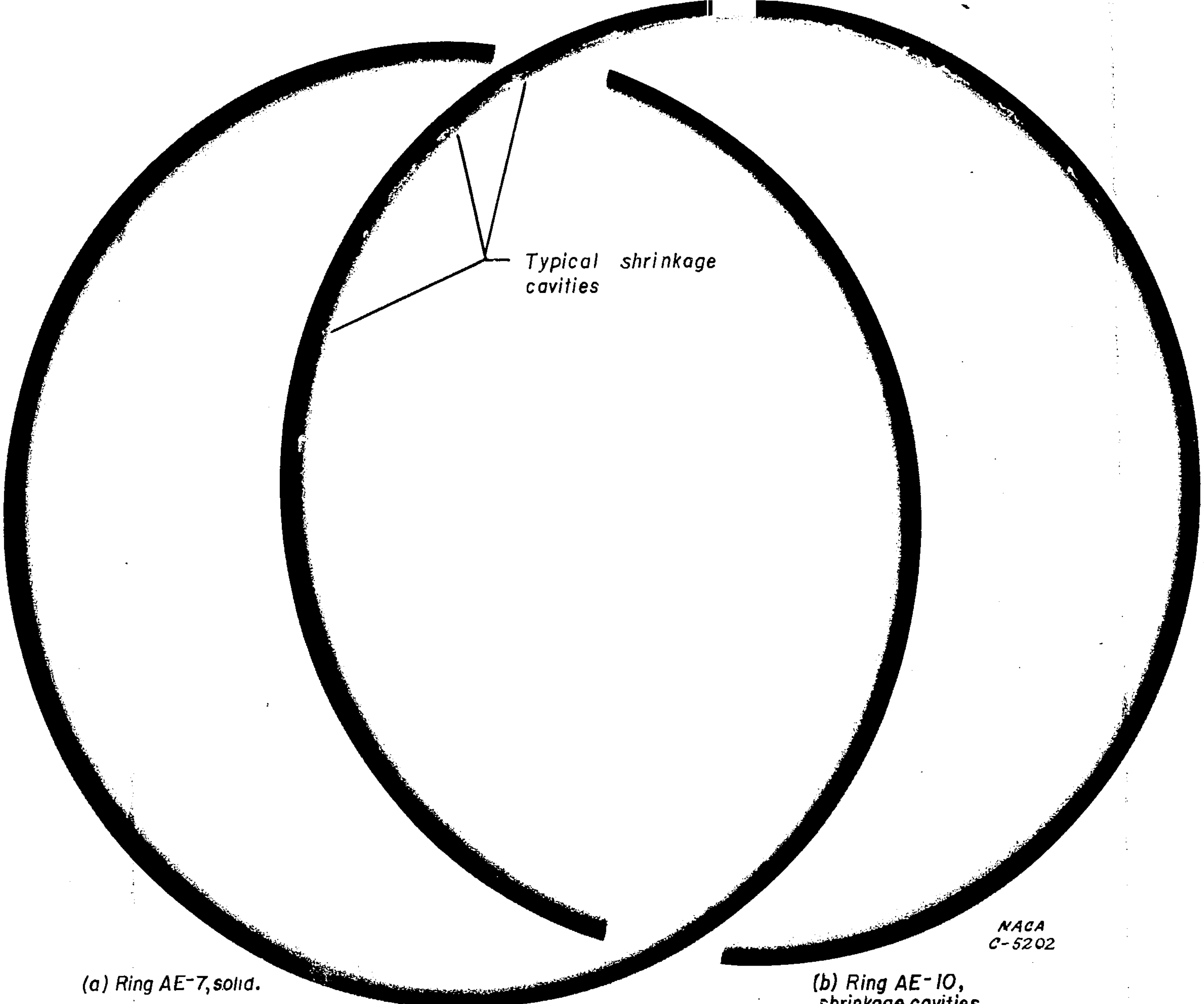


Figure 4.- Radiograph of ring AE-2 showing shrinkage cavities. Nominal tensile strength, 95,000 pounds per square inch.



(a) Ring AE-7, solid.

(b) Ring AE-10, shrinkage cavities.

Figure 5 - Radiographs of rings AE-7 and AE-10 showing shrinkage cavities in ring AE-10. Nominal tensile strength, 95,000 pounds per square inch.

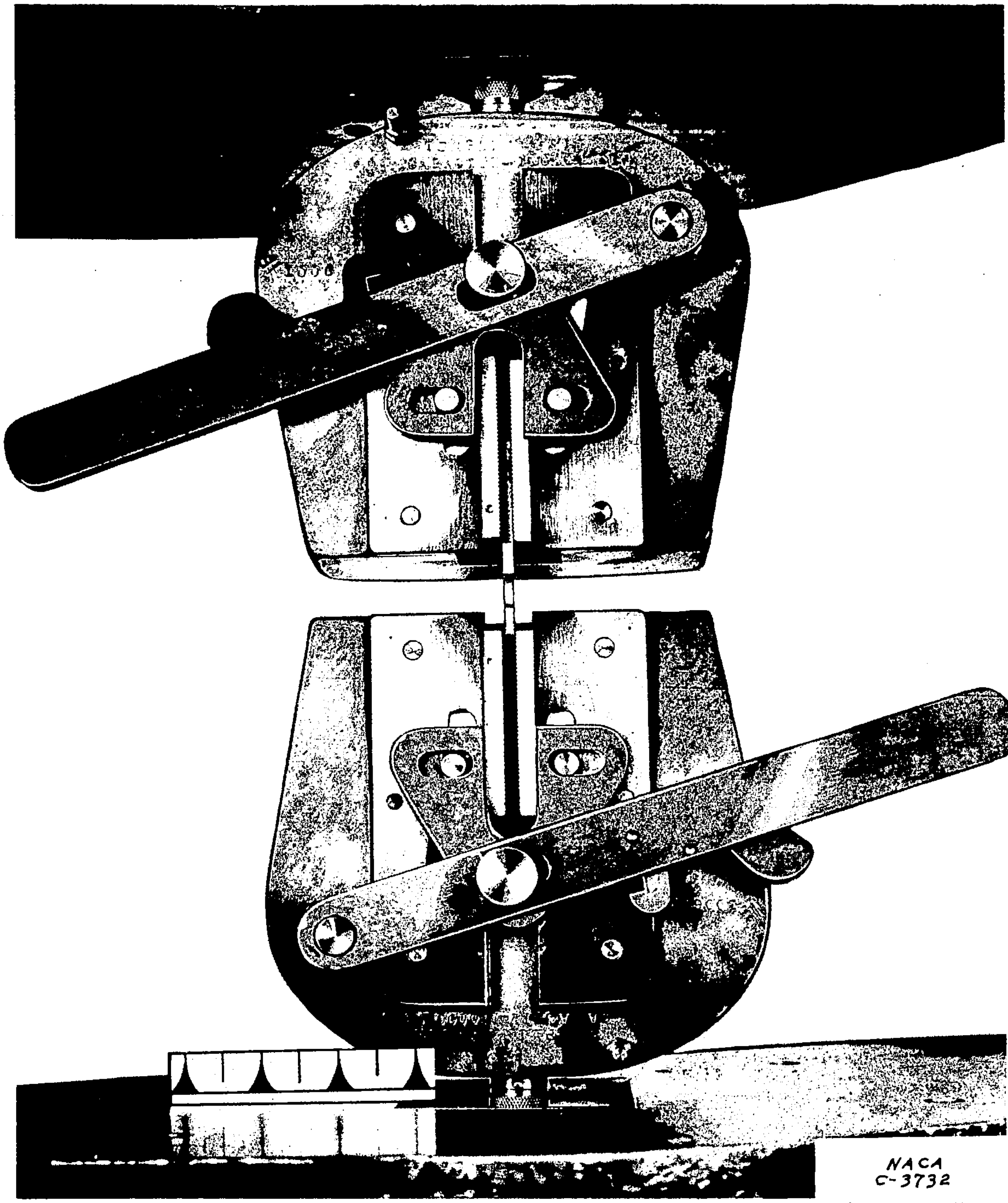


Figure 6. - Test setup showing the Templin grips and bar specimen.

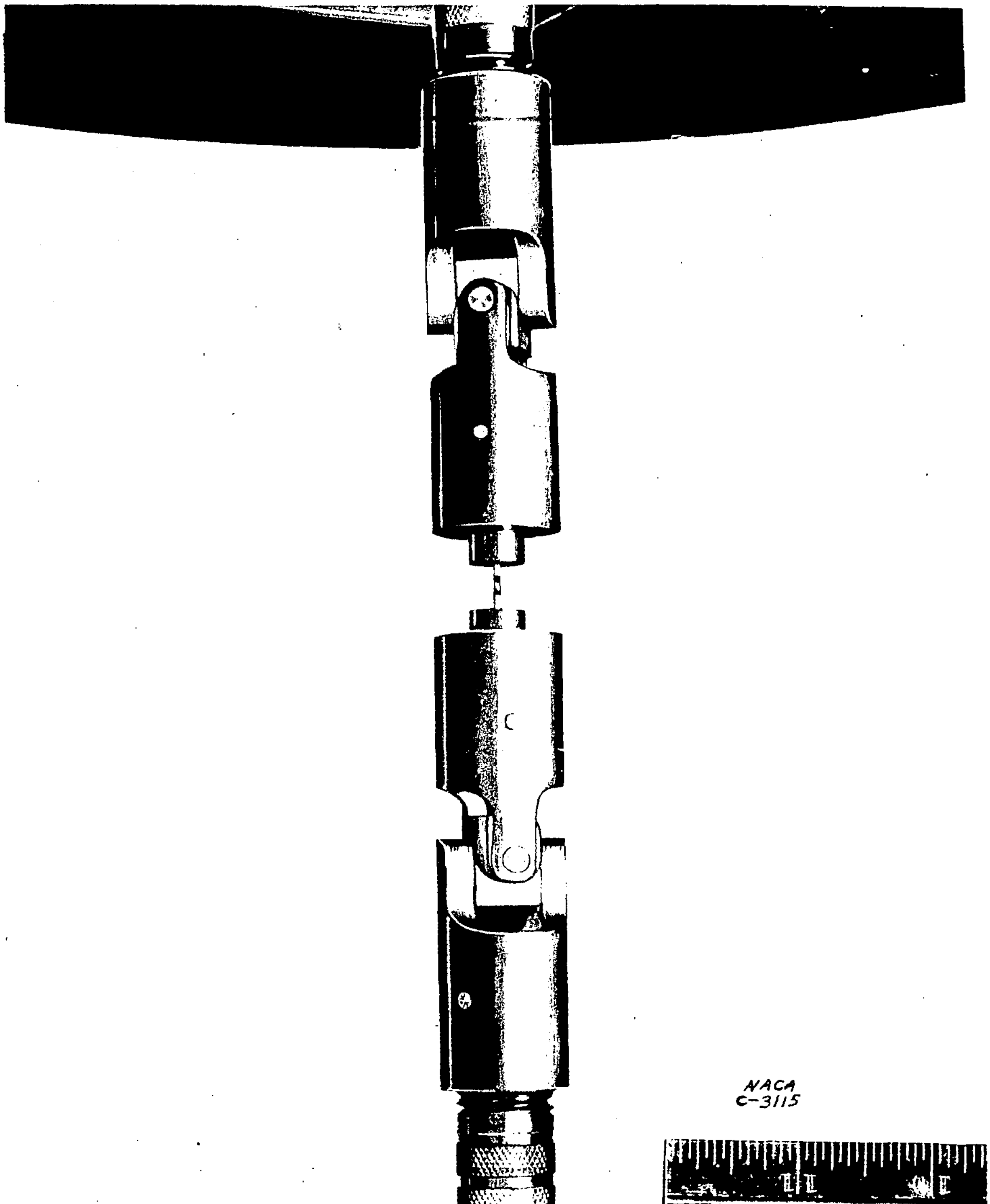


Figure 7. NACA microtensile-specimen test setup showing the universal joints, holders, and an NACA microtensile specimen.

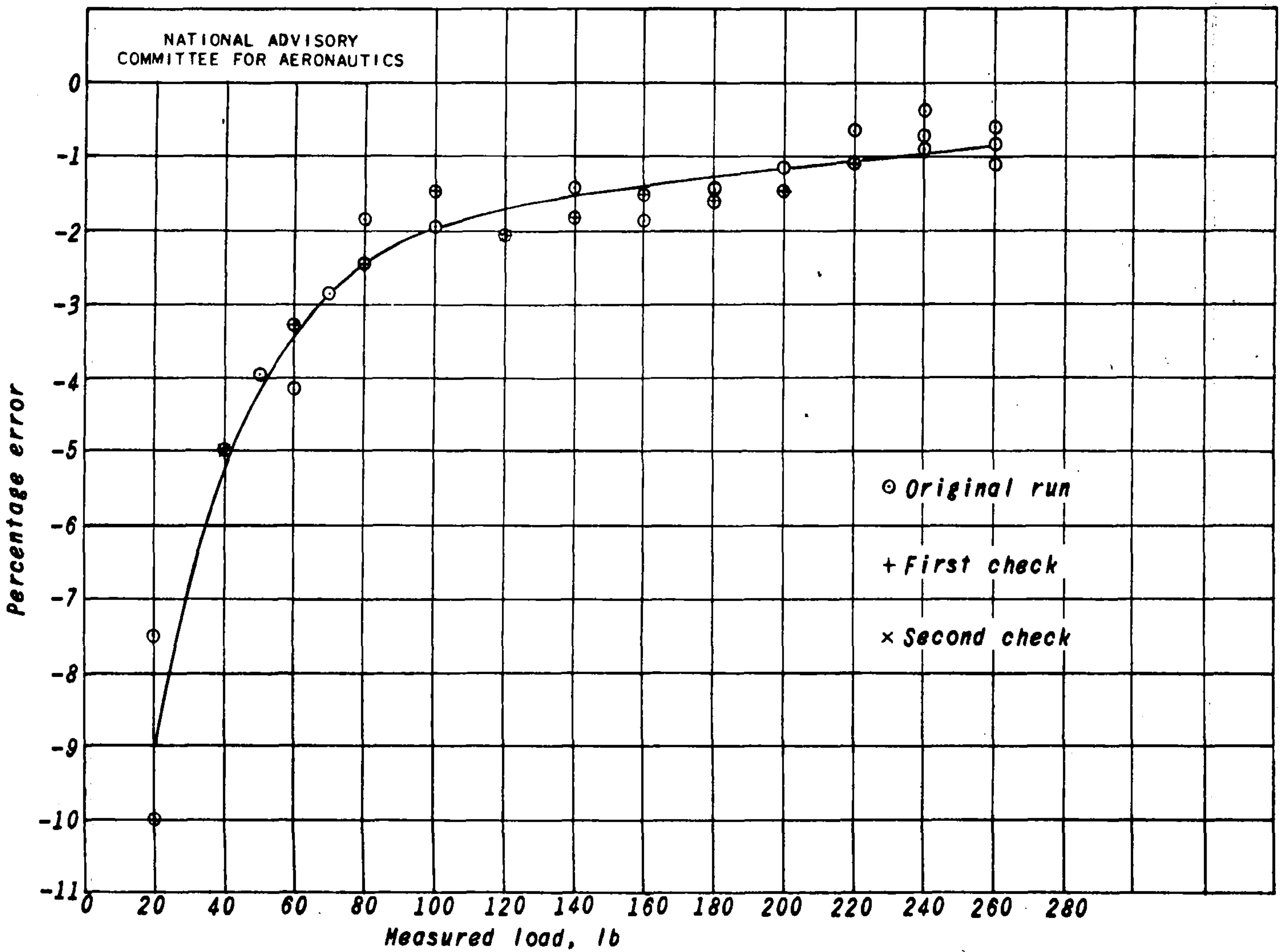


Figure 8. - Calibration curve for 120,000-pound universal testing machine. Scale range, 1200 pounds. Actual load = machine reading $\left(1 - \frac{\text{percentage error}}{100}\right)$.

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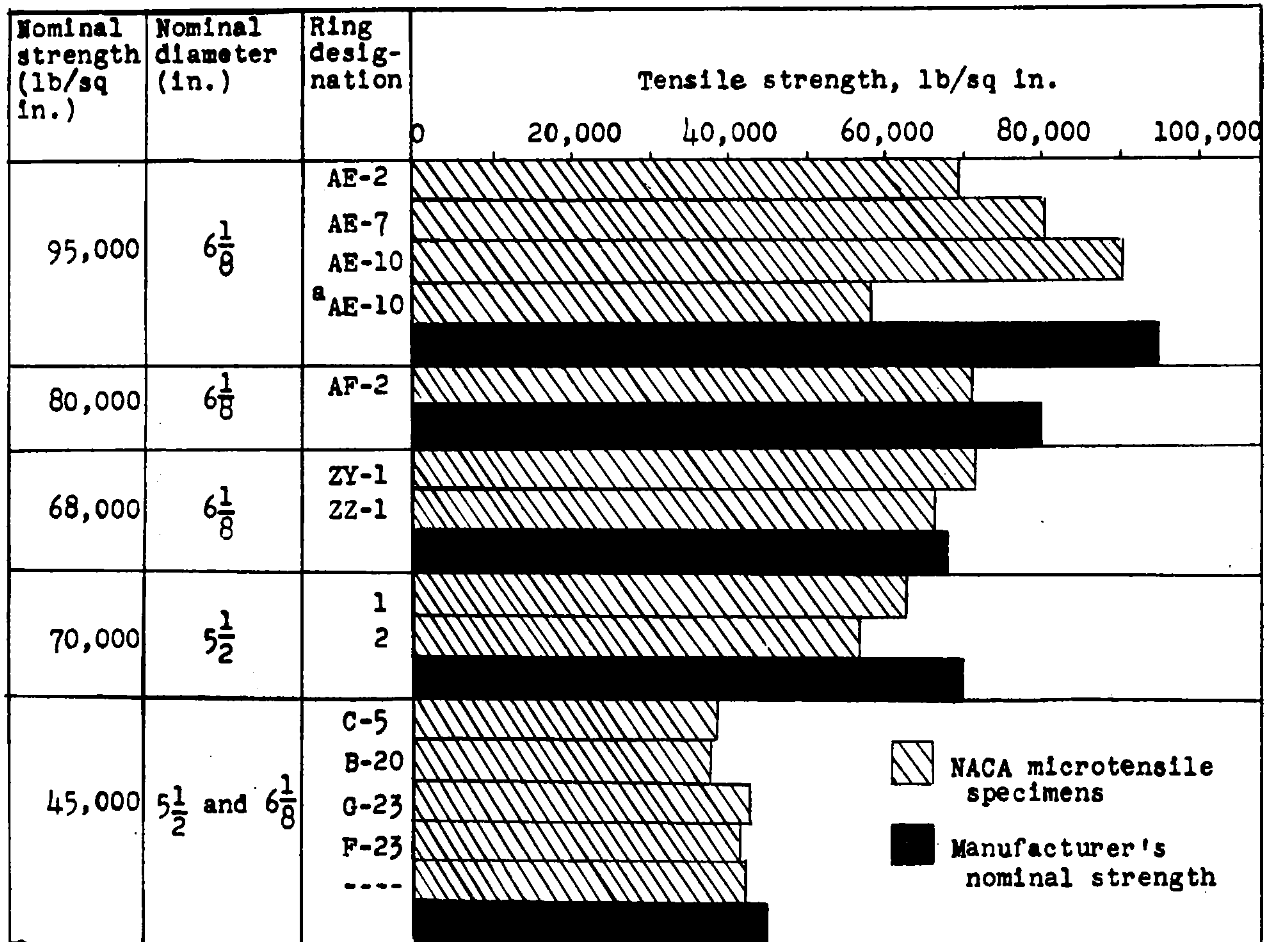


[a] Sections showing shrinkage cavities.

Figure 9.- Average results of tensile tests on NACA microtensile cast-iron specimens from finished piston rings of 45,000, 68,000, 70,000, 80,000, and 95,000 pounds per square inch nominal tensile strength. (Data from table I.)

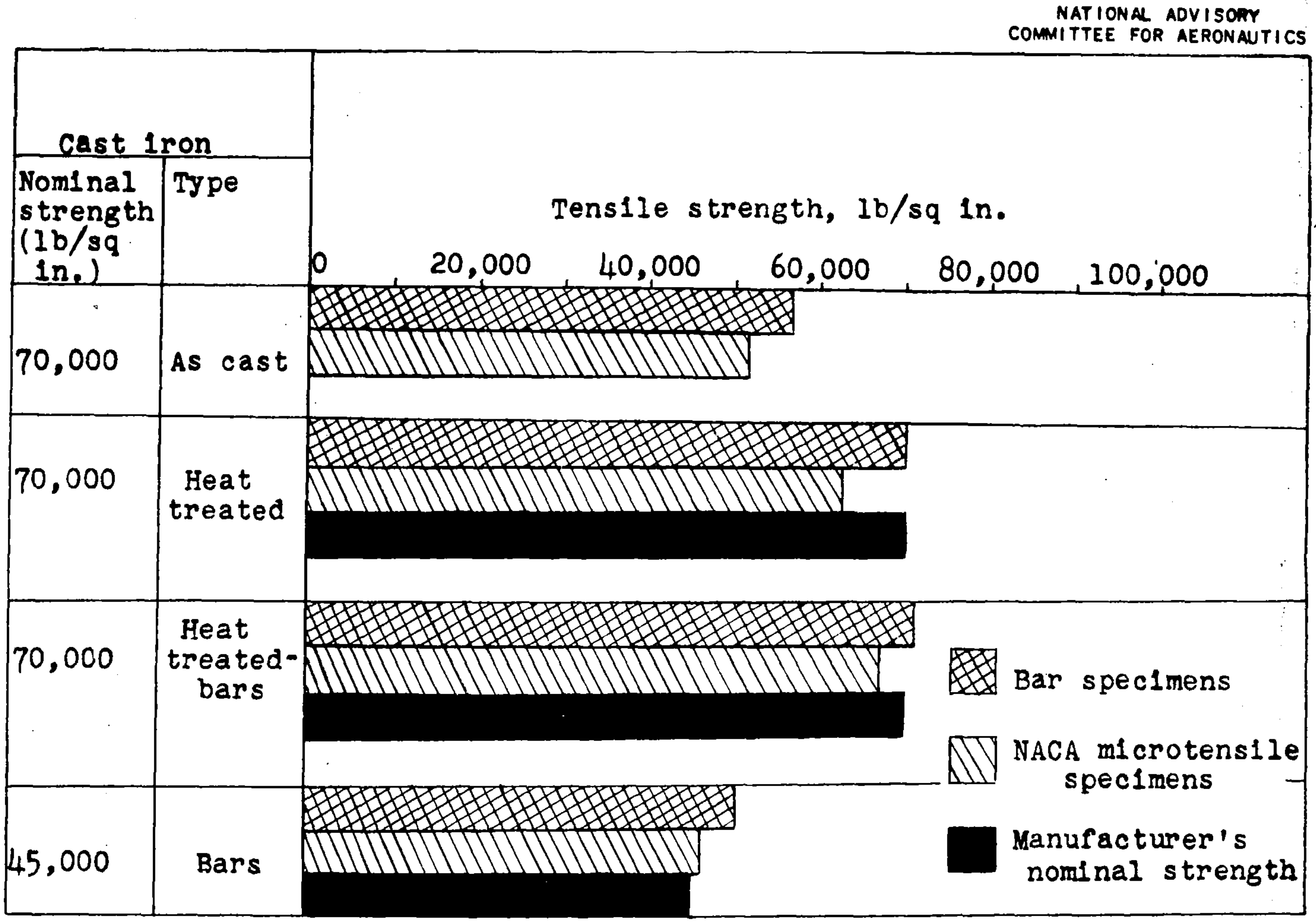
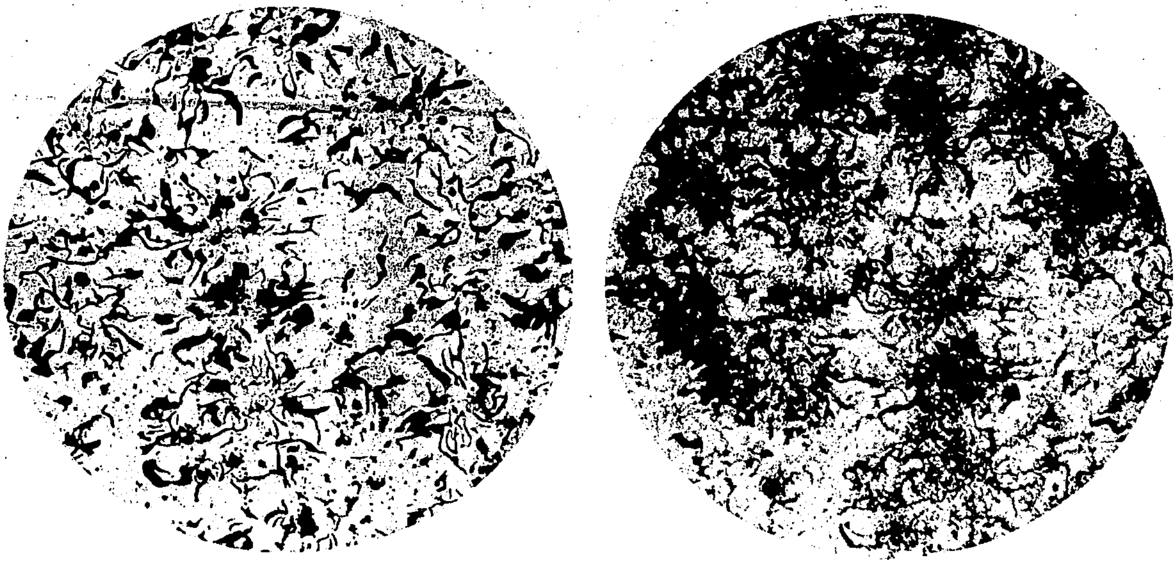
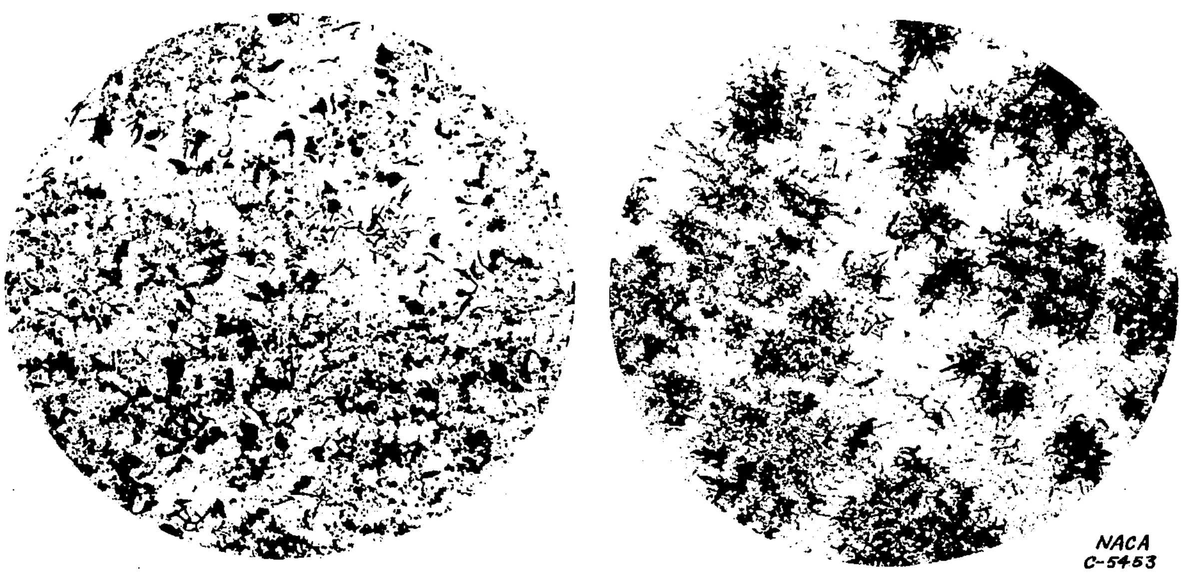


Figure 10. - Average results of tensile tests of NACA microtensile and bar cast-iron specimens from test castings of 45,000 and 70,000 pounds per square inch nominal tensile strength. (Data from table II.)



Unetched *Etched with 4-percent picral*

(a) Tensile strength, 50,500 pounds per square inch. X200.



Unetched *Etched with 4-percent picral*

(b) Tensile strength, 81,000 pounds per square inch. X200.

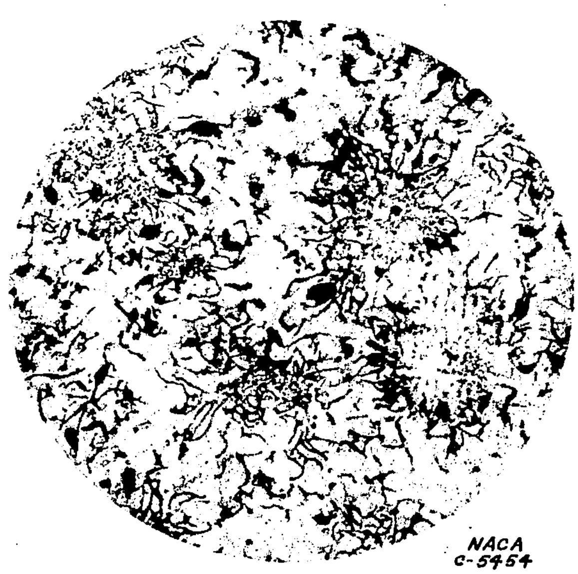
Figure 11. - Photomicrographs of specimens showing larger graphite-flake sizes for the specimens of lower tensile strength. All specimens were sectioned from cast iron of 70,000 pounds per square inch nominal tensile strength (as cast). Test casting 2.

Unetched

Etched with 4-percent picral

(a) Tensile strength, 61,500 pounds per square inch. X200.

Unetched



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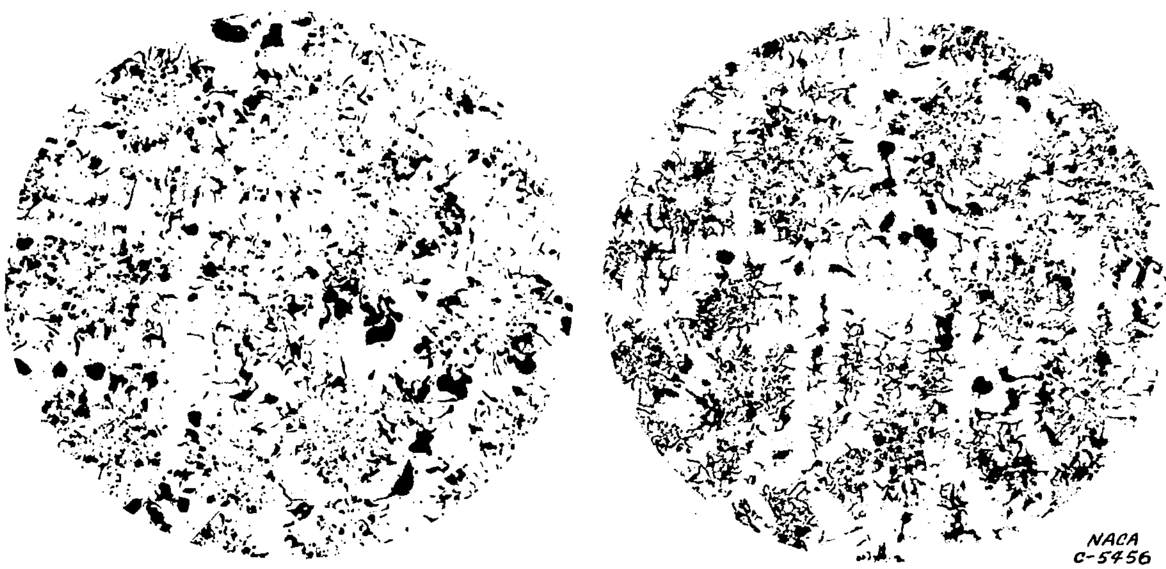
(b) Tensile strength, 74,800 pounds per square inch. X200.

Figure 12. - Photomicrographs of specimens showing larger graphite-flake sizes for the specimens of lower tensile strength. All specimens were sectioned from cast iron of 70,000 pounds per square inch nominal tensile strength (heat treated). Test casting 1.

Unetched *Etched with 4-percent picral*

(a) Tensile strength, 50,100 pounds per square inch. X200.



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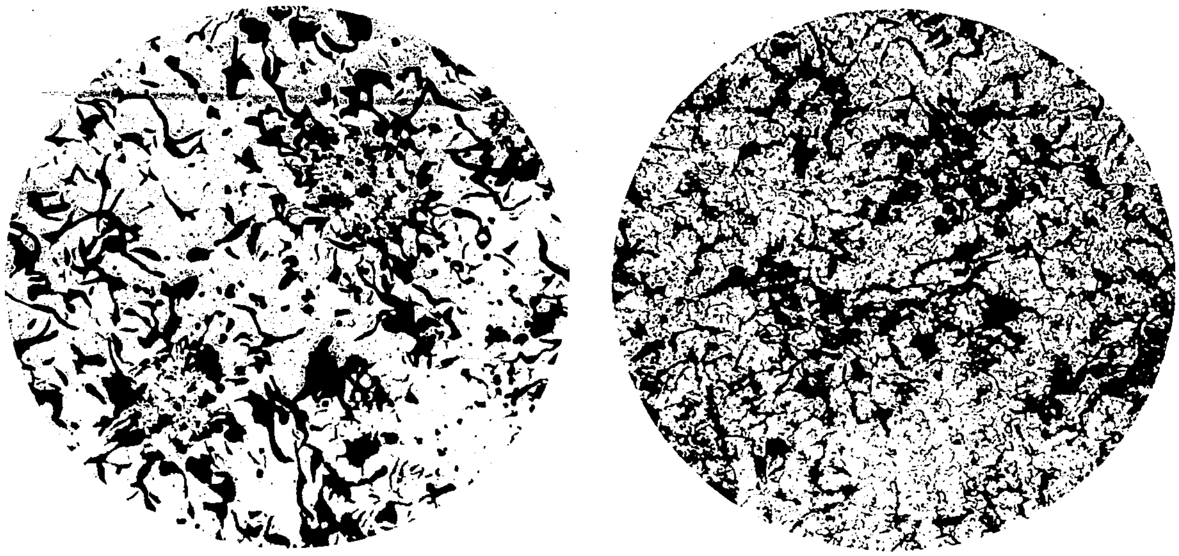
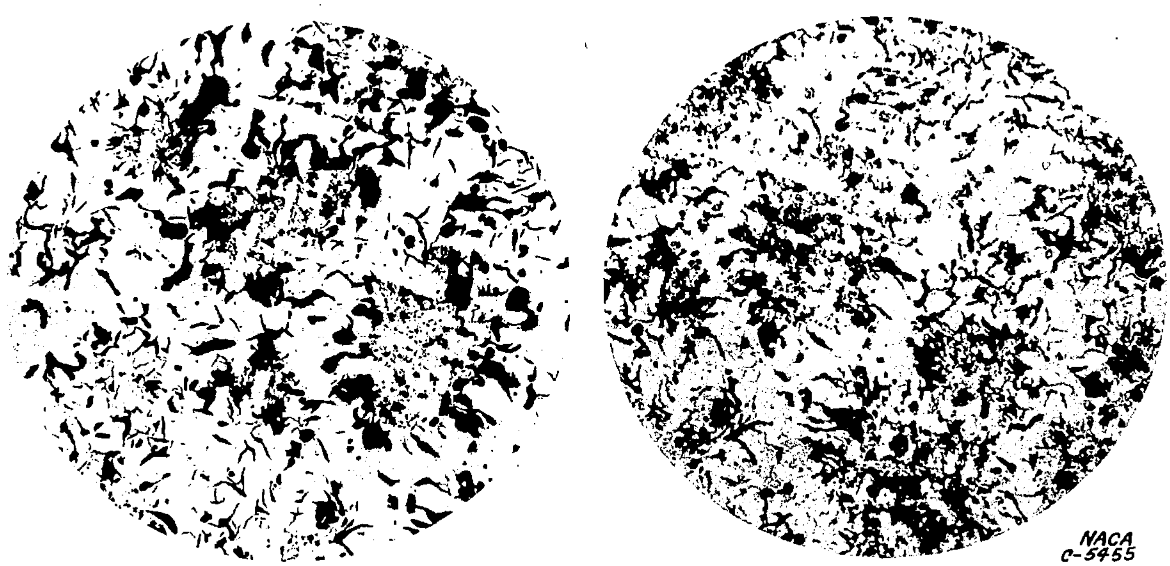
(b) Tensile strength, 73,400 pounds per square inch. X200.

Figure 13. - Photomicrographs of specimens showing larger graphite-flake sizes for the specimens of lower tensile strength. All specimens were sectioned from a heat-treated $5\frac{1}{2}$-inch-nominal-diameter finished piston ring of 70,000 pounds per square inch nominal tensile strength.



Unetched *Etched with 4-percent picral*

(a) Tensile strength, 58,300 pounds per square inch. X200.



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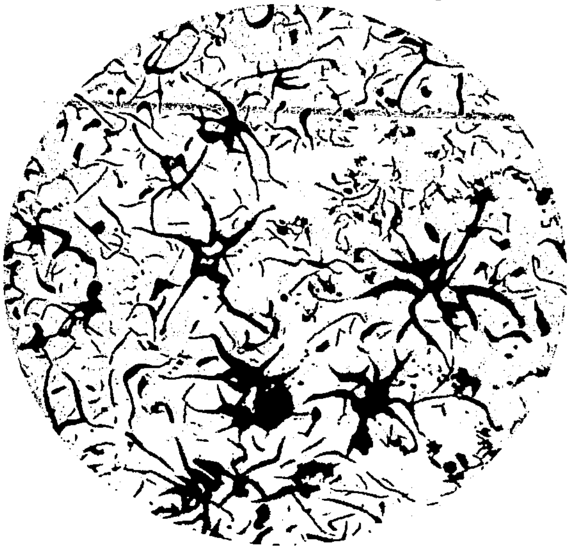
(b) Tensile strength, 72,300 pounds per square inch. X200.

Figure 14. - Photomicrographs of specimens showing larger graphite-flake sizes for the specimens of lower tensile strength. All specimens were sectioned from a finished piston ring of 68,000 pounds per square inch nominal tensile strength. Ring ZZ-1.



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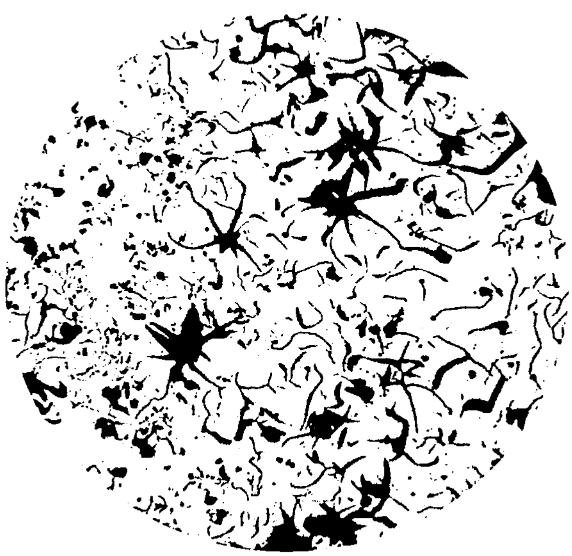
(a) Tensile strength, 34,000 pounds per square inch. X200.



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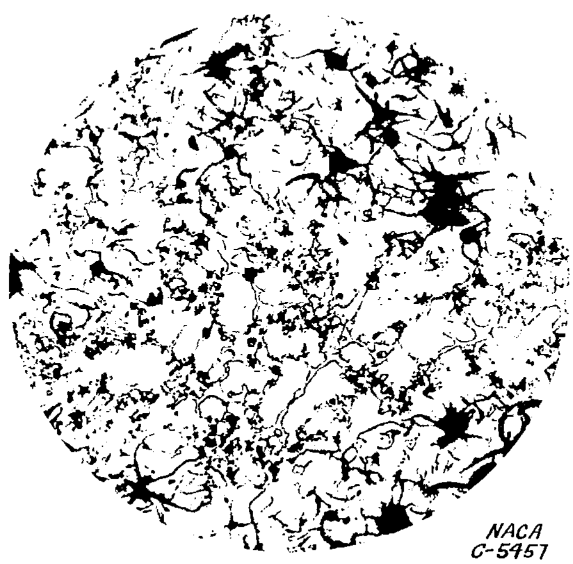

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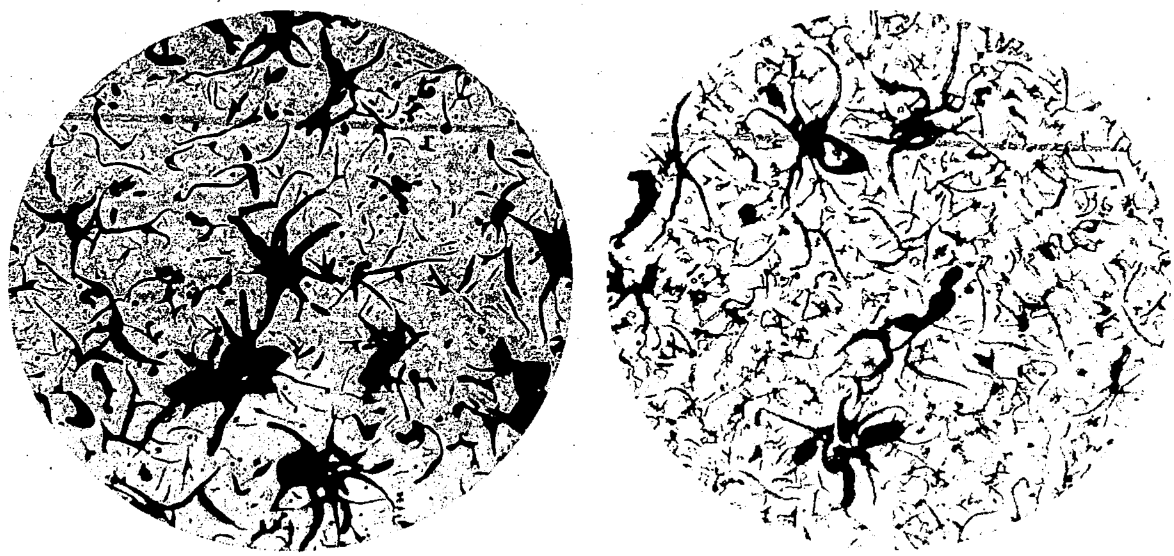
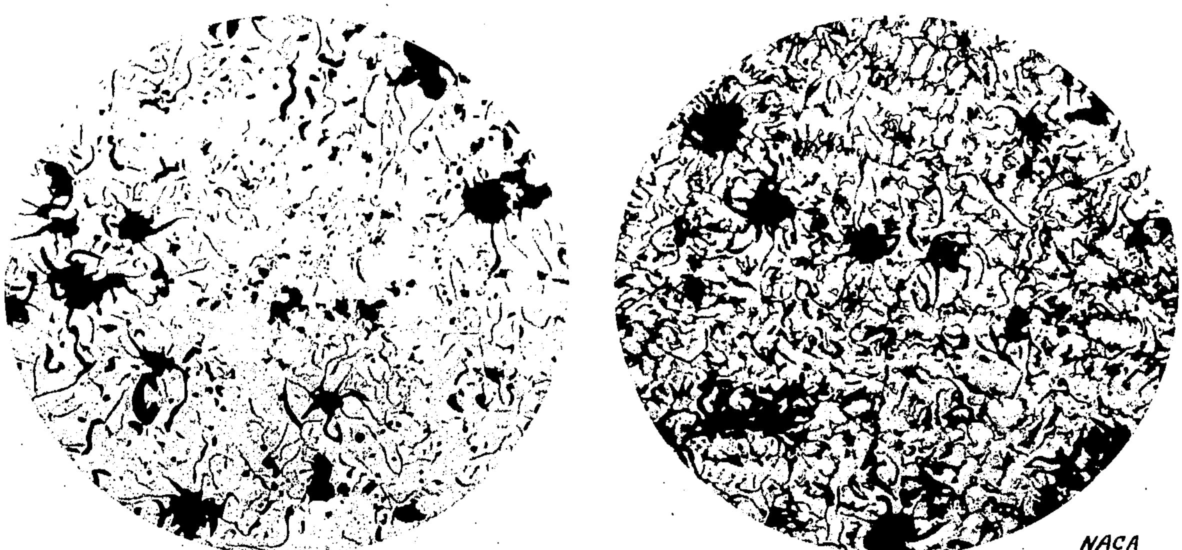
(b) Tensile strength, 41,300 pounds per square inch. X200.

Figure 15. - Photomicrographs of specimens showing larger graphite-flake sizes for the specimens of lower tensile strength. All specimens were sectioned from a finished piston ring of 45,000 pounds per square inch nominal tensile strength. Ring C-5.



Unetched *Etched with 4-percent picral*

(a) Tensile strength, 32,000 pounds per square inch. X200.



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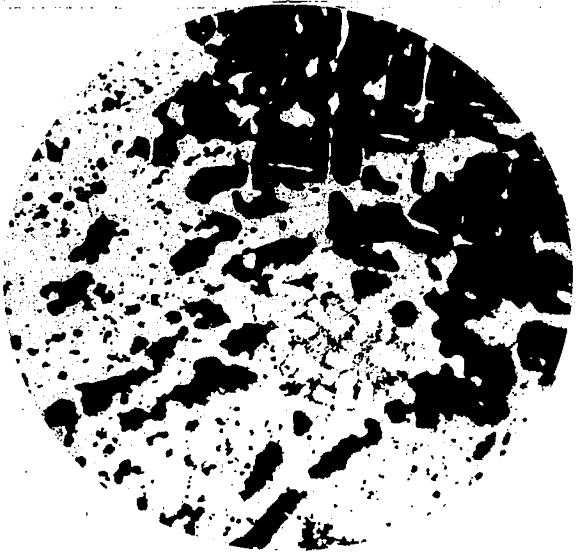
(b) Tensile strength, 45,600 pounds per square inch. X200.

Figure 16. - Photomicrographs of specimens showing larger graphite-flake sizes for the specimens of tensile strength. All specimens were sectioned from a finished piston ring of 45,000 pounds per square inch nominal tensile strength. Ring B-2.



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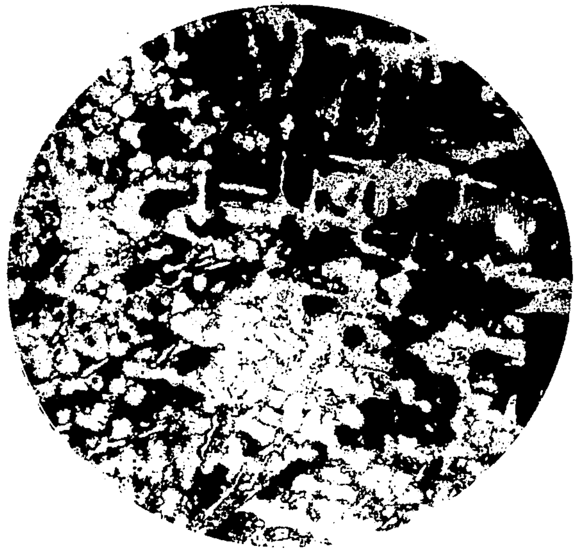

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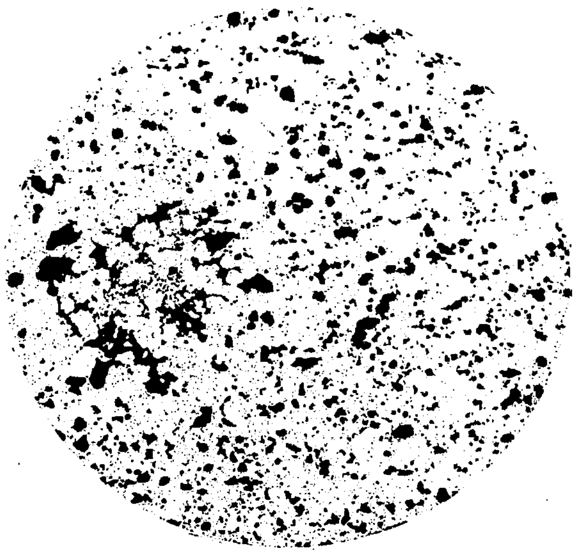
(a) Representative sample showing defects in the form of shrinkage cavities. Tensile strength, 60,600 pounds per square inch. X200.



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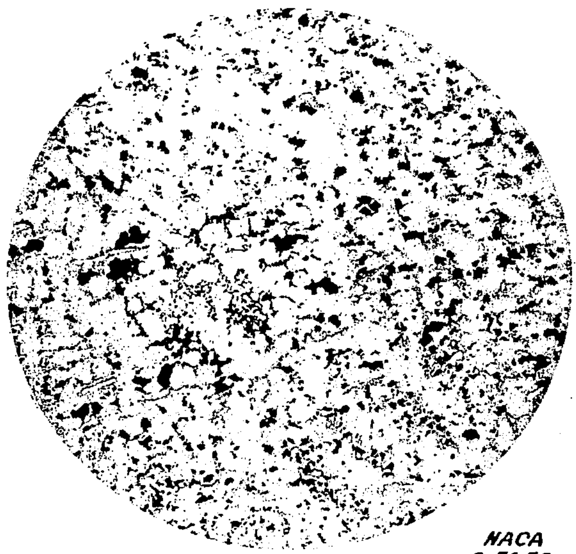

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(b) Representative sample of defect-free section from same ring as (a). Tensile strength 95,000 pounds per square inch. X200.

Figure 17. - Photomicrographs of specimens showing the difference in microstructure between high and low tensile-strength specimens. All specimens were sectioned from a finished piston ring of 95,000 pounds per square inch nominal tensile strength. Ring AE-2.